Possible Integrated

8 GeV Program

after the Tevatron Collider Era

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Stolen from Chuck Ankenbrandt and Milorad Popovic

NP08

Central Question:

- How Does Muon Program fit with other FNAL Options before and during Project X era?
- Can we build a consistent program at the Intensity Frontier together with our Neutrino Oscillation Program?

- Disclaimers:
  - This is one possible plan and I will show options within the overall structure
  - Not thoroughly reviewed or part of any official FNAL plan
  - "Existence" Argument and a possible way to think about integrated program
  - This plan *not* consistent with antiproton program
    - Uses existing Accumulator/Debuncher
    - therefore would need another ring

Theme:

- FNAL has multiple 8 GeV rings:
  - Booster
  - Accumulator
  - Debuncher
  - Recycler
- This gives us considerable flexibility in manipulating beam time structure and overcoming limitations of any individual ring
- Allows us to run Neutrino Program at 120 GeV at the same time as 8 GeV program

Remainder of Talk:

- Proposed Experiments
- Physical Layouts and Beam Transfer Schemes
  - Three phases in development:
    - Booster Era (current arrangement after TeV shutdown)
    - Project X Era (Beam Power = 200 kW @ 8 GeV)
    - Upgraded (2MW) Project X Era Experiments
- Issues to Consider:
  - Possible Locations for Experiments
  - Beam Requirements
  - Providing the required proton time distributions
- Summary

Experiments and Their Requirements

- Various groups would like to do experiments made possible by intense 8-GeV proton beams:
  - Muon-to-electron conversion
  - Muon g-2
  - K -> $\pi \nu \bar{\nu}$ (with neutral and charged kaons)
  - Muon test beams
  - Neutrino factories based on muon storage rings
  - Muon colliders
  - Accelerator physics research and development
- Experiments want to start as soon as possible!
- Many want to start at lower beam power and then upgrade to high beam power, learning as they go
- **Different Experiments need different time distributions for the proton beam: must deal with incompatibilities.**

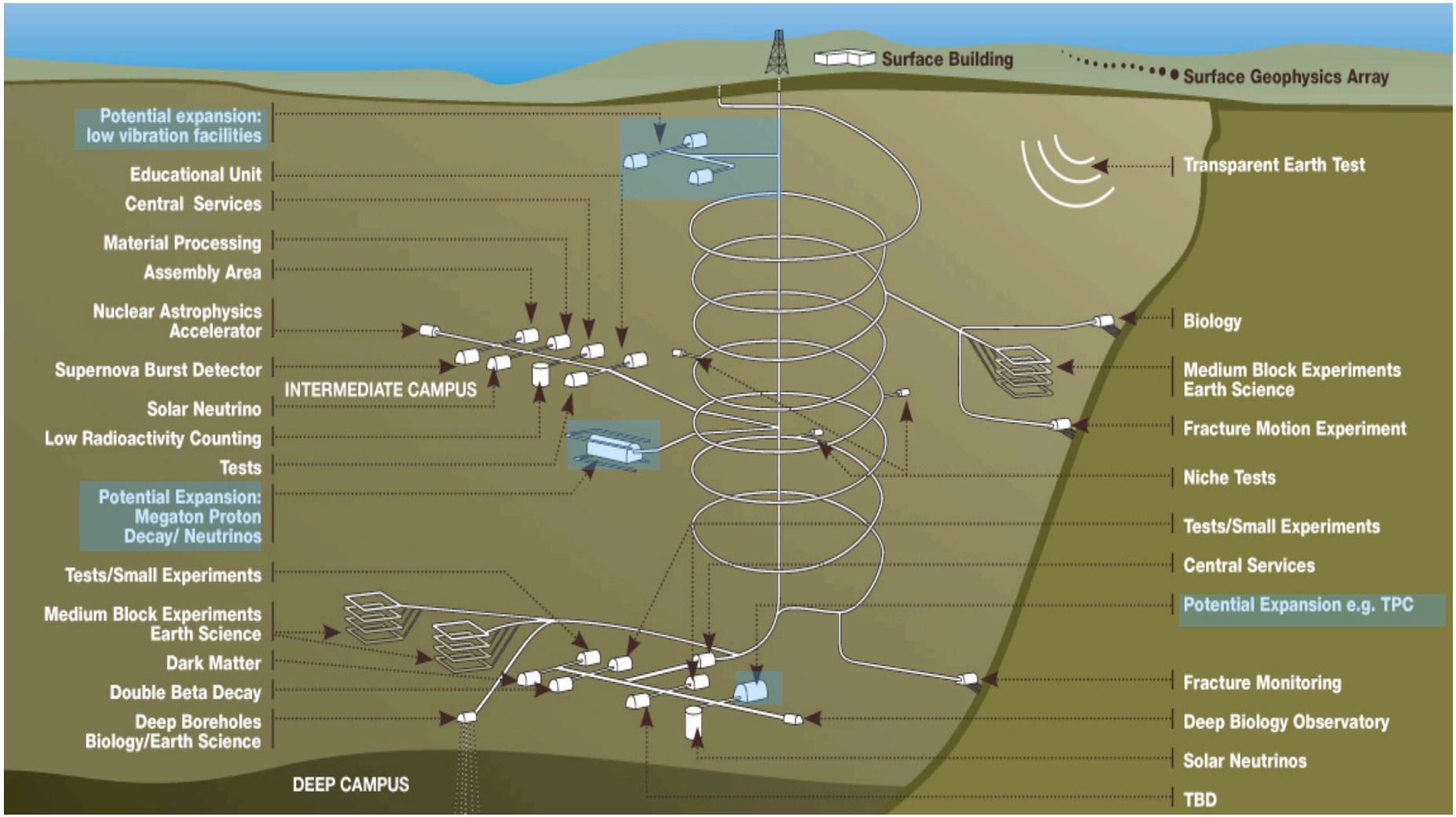
Layouts and Beam Transfer Schemes

- Booster Era (≈25 kW @ 8 GeV)
  - Mu2e, g-2, Nova (120 GeV)
- Project X Era (Beam Power ≈200 kW @ 8 GeV)
  - Mu2e, g-2, Kaons,… and NovA at 120 GeV
- Upgraded (≈2MW) Project X Era
  - Upgrade all 8 GeV experiments and Nova?
  - DUSEL? (Deep Underground Lab at Homestake)
    - proton decay @ 10^{35} yr + neutrino oscillations
    - Liquid Argon (100 kT) or Water Cerenkov (1 Mton?)
    - See Neutrino Session (also Project X workshop at FNAL)

http://www.fnal.gov/directorate/Longrange/Steering_Public/workshop-physics-2nd.html

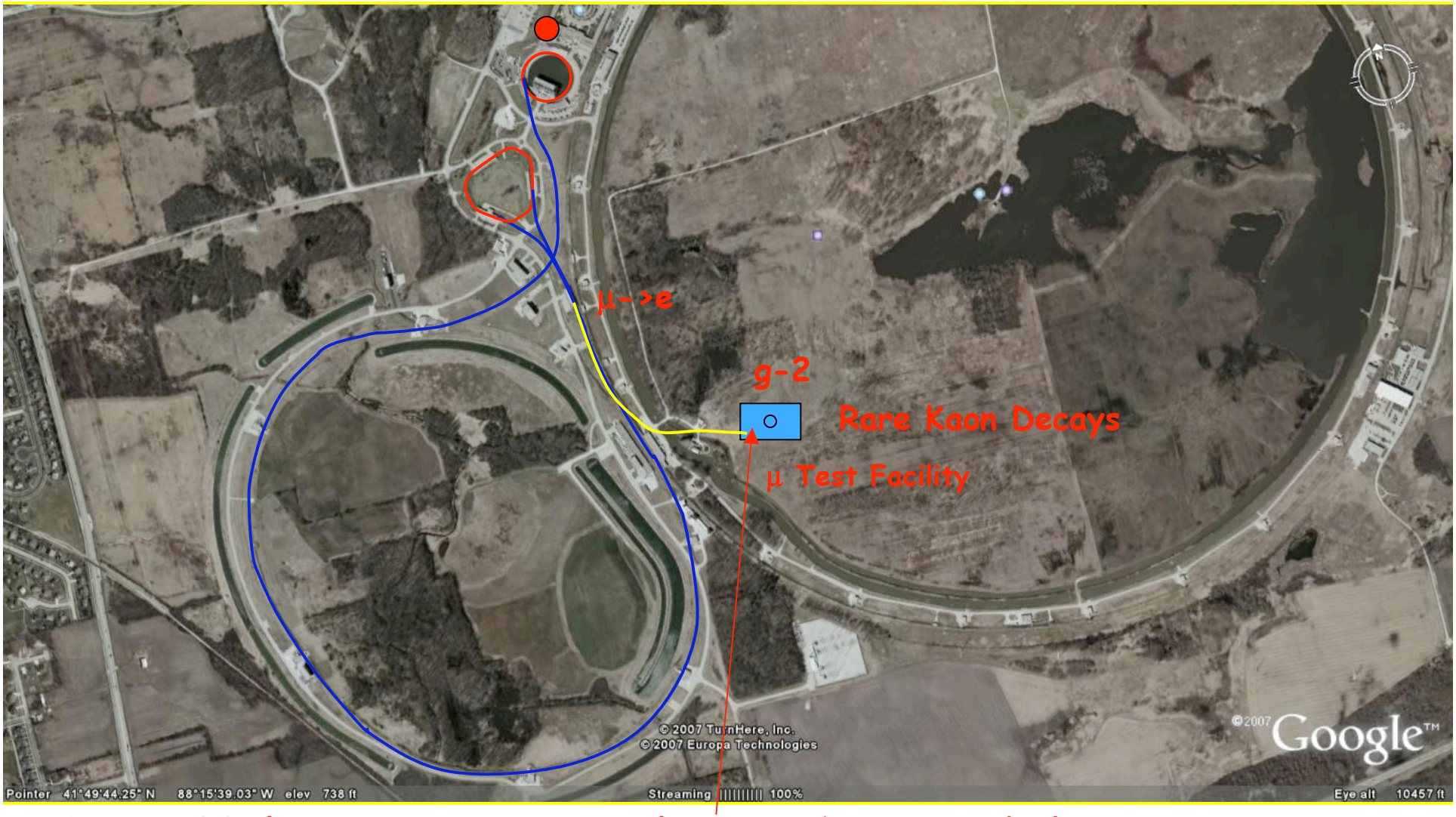
A Schematic View of DUSEL

A schematized view circa 2015 + possible expansions



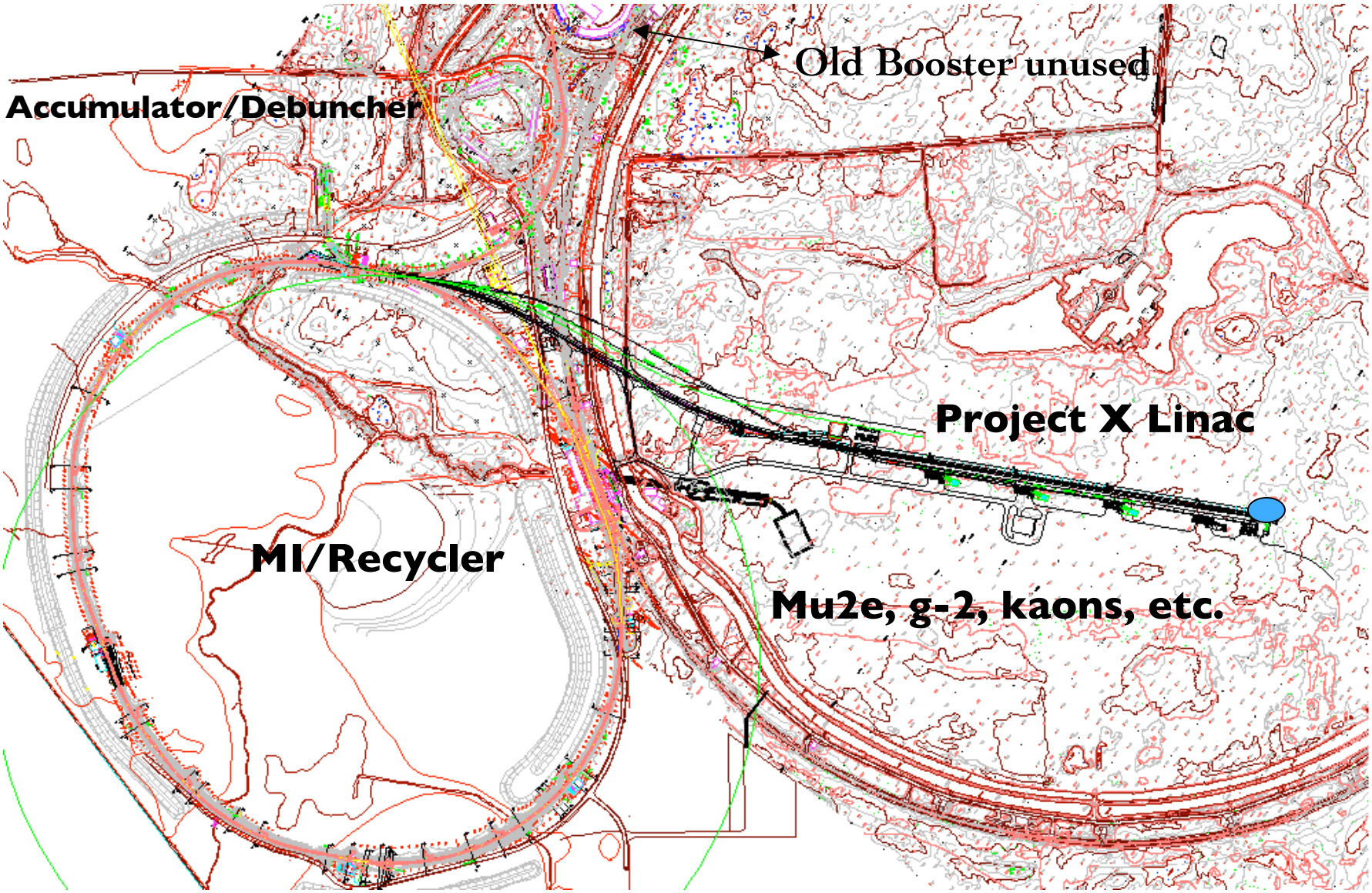
From J. Kotcher

Booster-era Beam Transfer Scheme



New 200-kW target station that can be upgraded to >2 MW

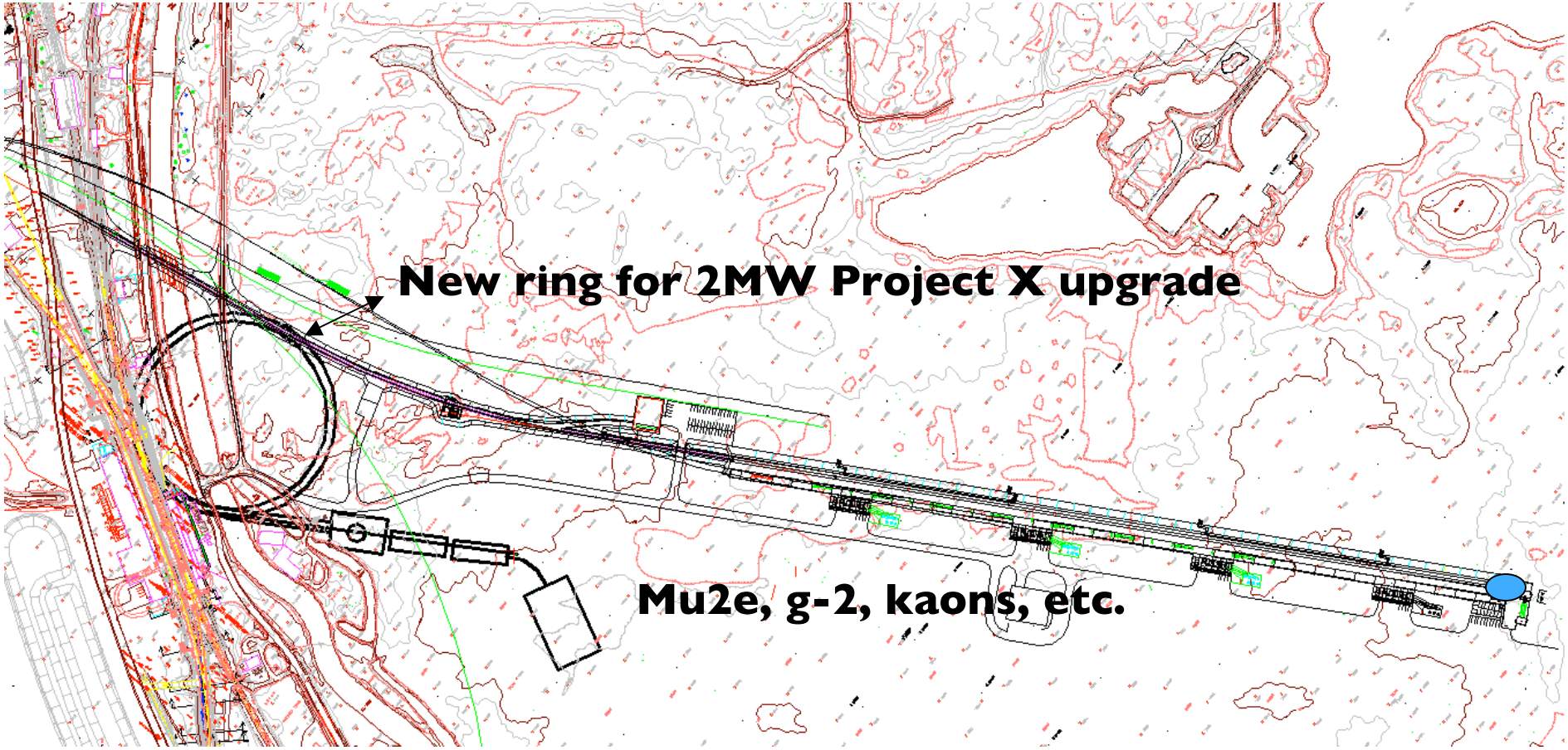
Beam Path to 200kW target station in Project X Era



New Ring for 2 MW Era

- Probably can't upgrade Accumulator/Debuncher much past 200 kW
- Therefore will need new ring to perform beam structure manipulations

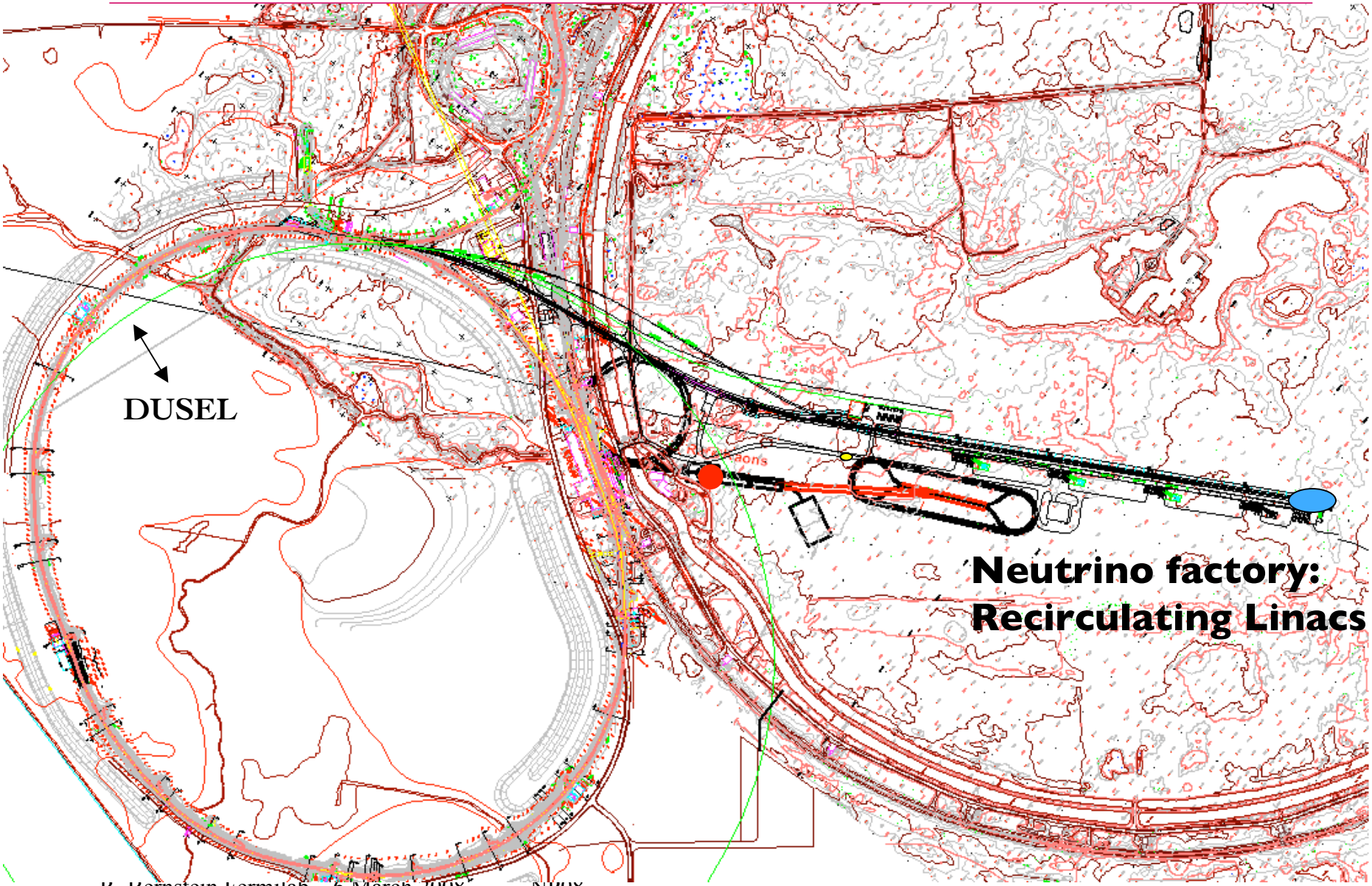
Beam Path to 2 MW target station in Project X Era



Beam In Upgraded Project X Era

- Possible Neutrino Factory
- Beam from Project X Linac into 2 MW station, making muons
- Then many choices
  - Mu2e
  - g-2
  - Kaons
  - Into recirculating linacs for neutrino factory
  - Neutrinos off to DUSEL?

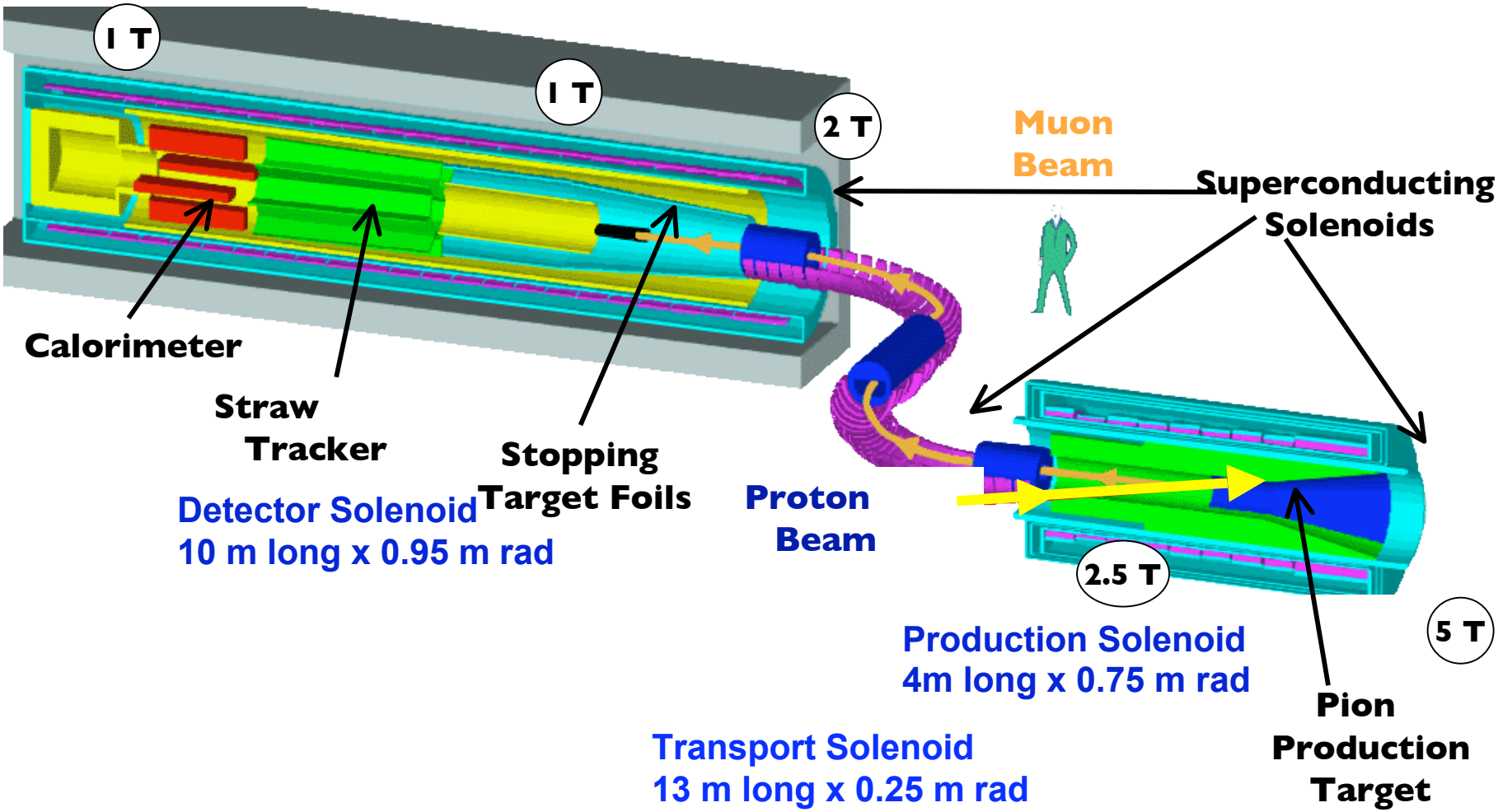
Path of Beams to 4 GeV ν Factory in Project X Era



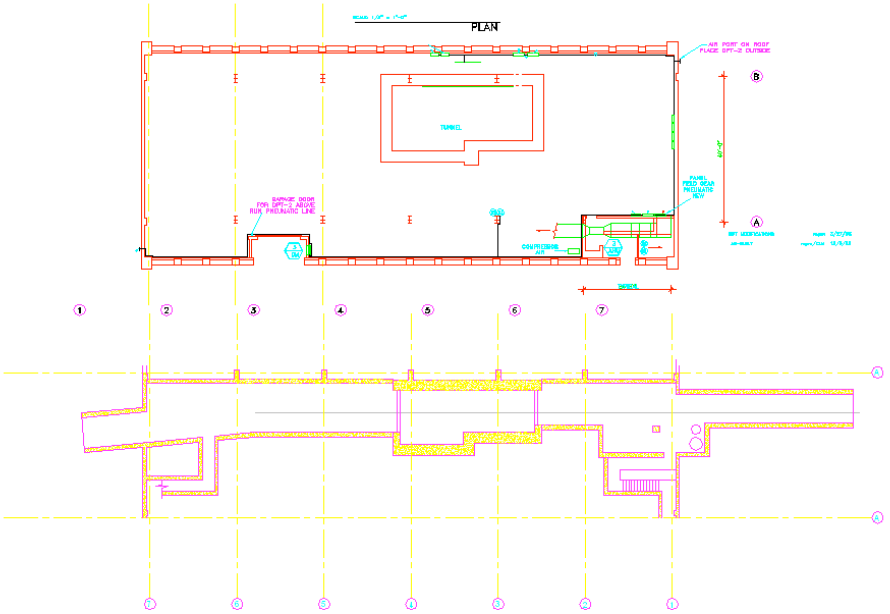
The Experiments

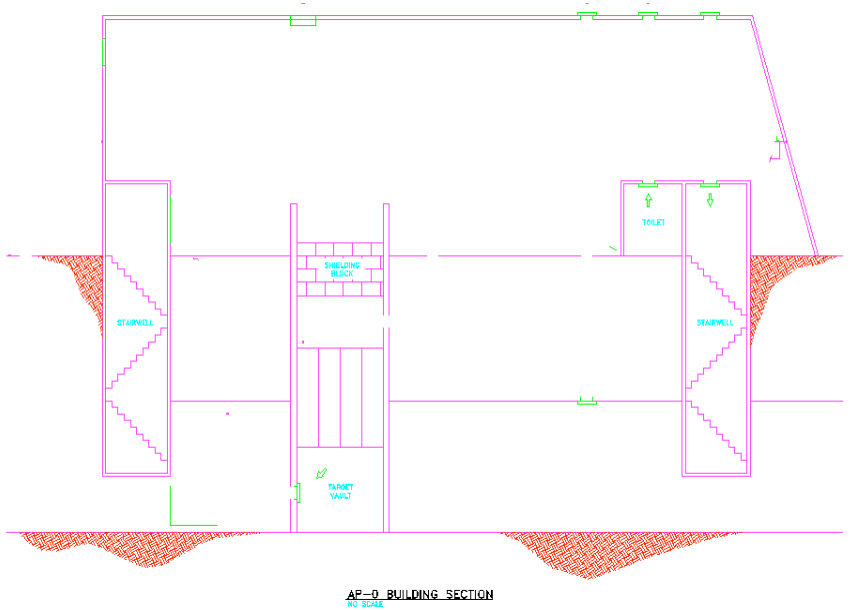
- Muon-to-electron conversion
- Muon g-2
- $K \rightarrow \pi \nu \nu$ (with neutral and charged kaons)
- Muon test beams
- Neutrino factories based on muon storage rings
- Muon colliders
- Accelerator physics research and development

mu2e Apparatus

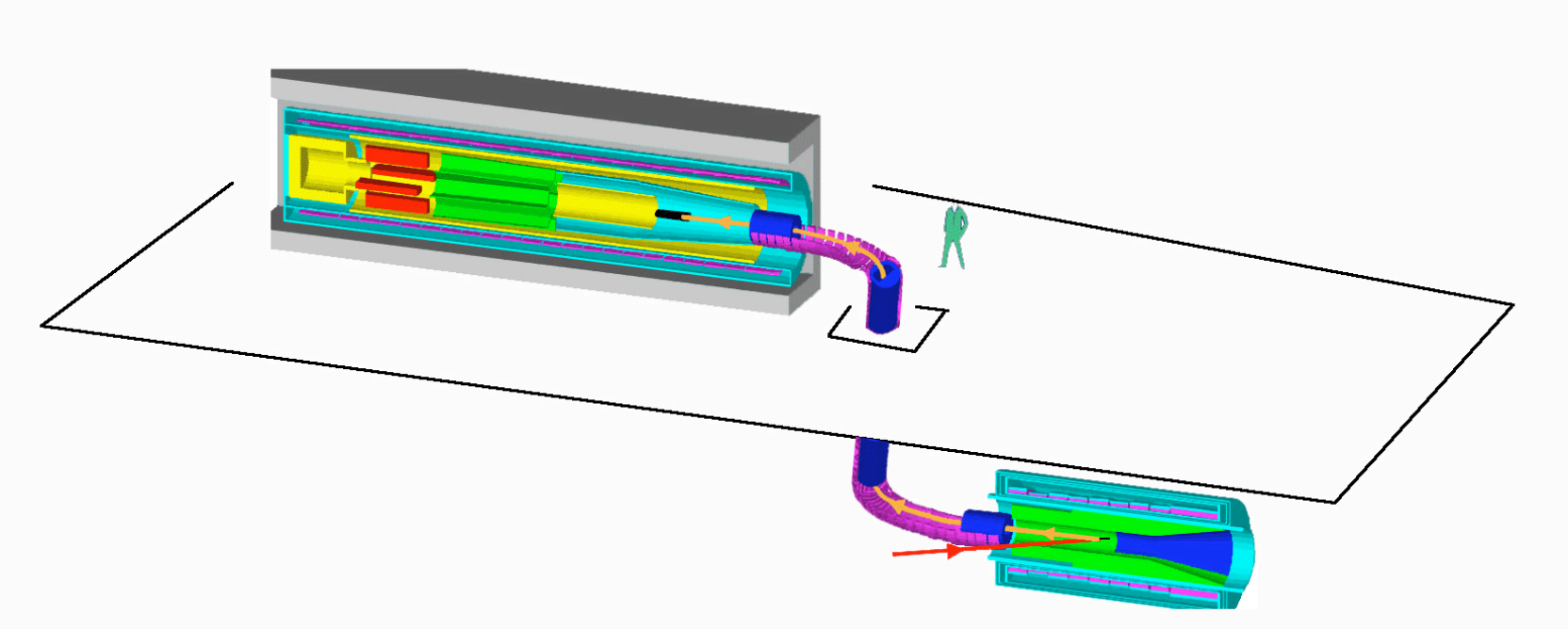


AP0-target station: Possible Home for Mu2e





mu2e Apparatus Oriented Vertically



Vertical offset is about 6 meters

Need to rotate apparatus to fit in AP0

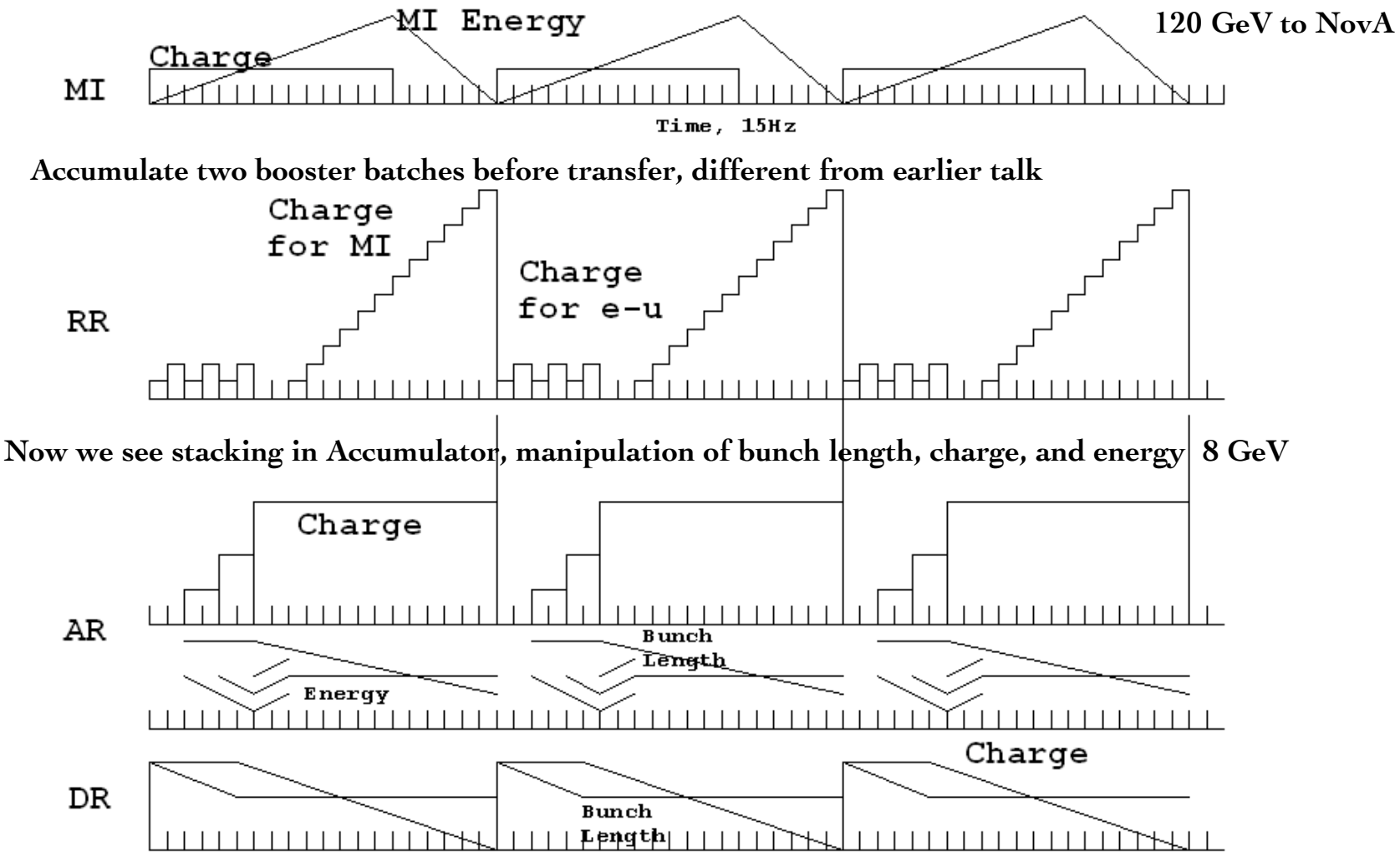
Mu2e and g-2

- Have Chosen to make civil construction as simple as possible: new tunnel from Debuncher to Experiments
- How Do We Get Beam to both Mu2e and g-2?
  - Let's say mu2e upstream…
    - Can remove beam stop in mu2e?
      - (but beam stop part of return yoke)
  - Can Build bypass (not shown)
- Beam Requirements *not* compatible
  - Experiments need to run at different times, or in different cycles
- Have Chosen Schemes that keep < 200 kW in Accumulator, Debuncher
  - Variety of Schemes Possible; will show two
- If Upgrades to Project X > 200 kW, probably new ring to replace Accumulator/Debuncher

Beam Requirements for mu2e Experiment

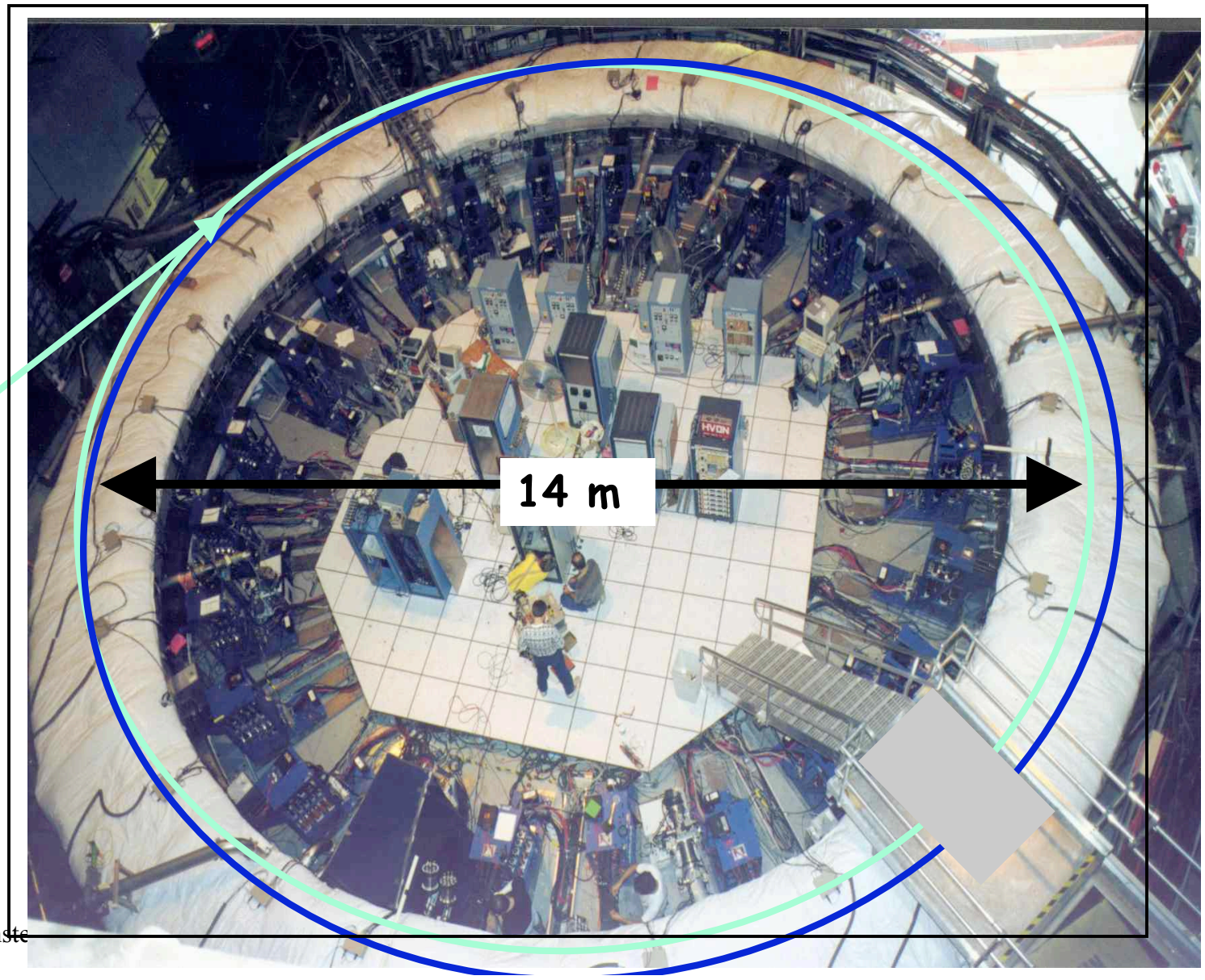
- Beam Power
  - Booster era: ~ 25 kW
  - Project X era: ~ 100 kW (~200 kW with upgrade)
- Proton time distribution
  - Slow spill with high duty cycle
    - Bunch length <~ 100 nsec(minimize prompt backgrounds)
    - Bunch separation 1.7 μsec (μ lifetime)
- Creating the proton distribution in Booster era
  - Momentum-stack three Booster batches in Accumulator
  - Rebunch into one ~100 nsec bunch
  - Single-turn transfer single bunch to the Debuncher
  - Slow spill resonantly from the Debuncher
    - Resonant slow spill: make beam a little unstable transversely, near harmonic; protons leave core and directed to another beamline
  - Repeat the above sequence twice per MI cycle

Booster-Era Beam Timelines for mu2e Experiment



The Muon g-2 Experiment at BNL

(Can be relocated to Fermilab)



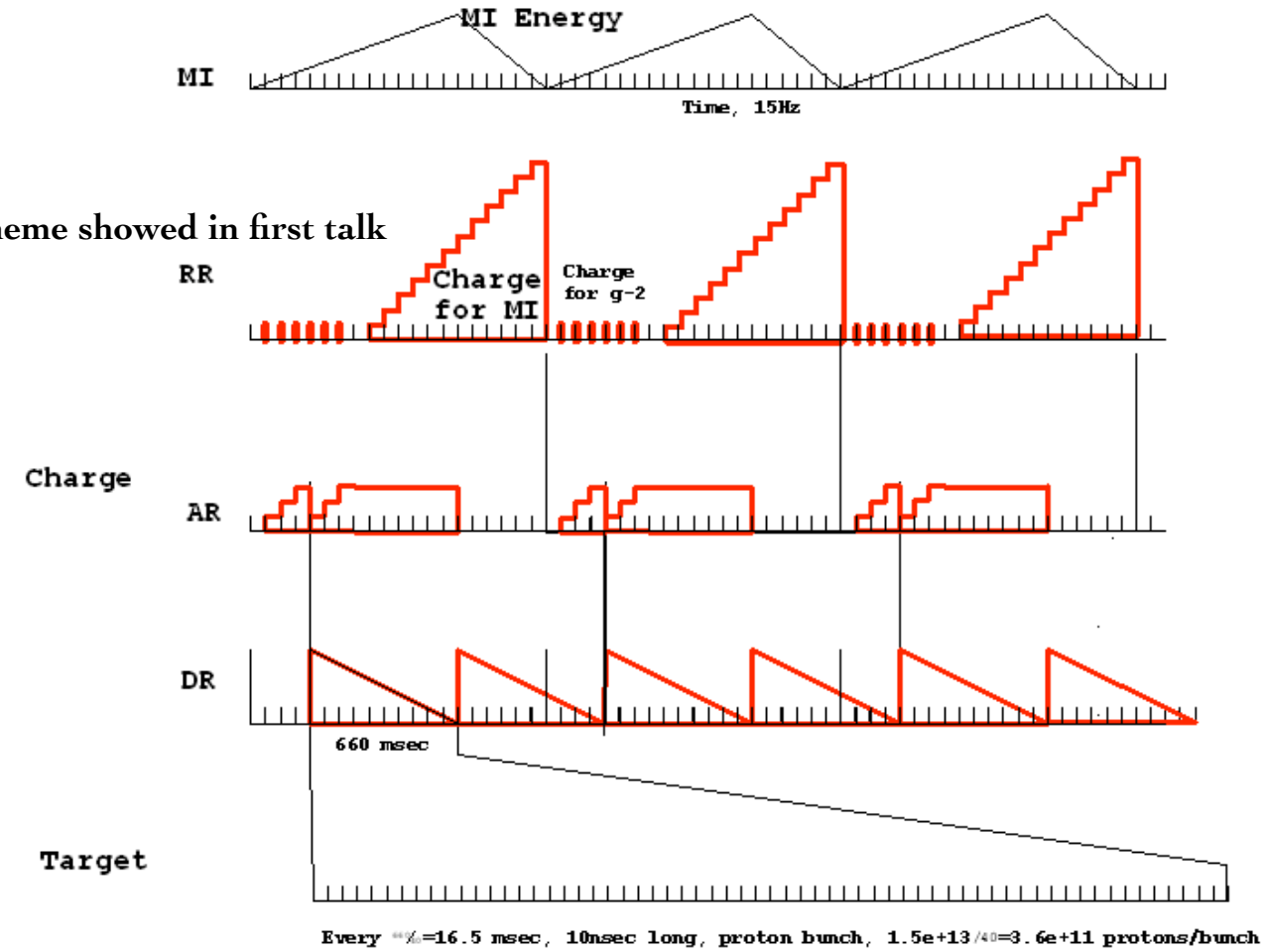
Beam Requirements for g-2 Experiment

- Proton beam power
  - Booster era: ~ 25 kW
  - Project X era: up to 200 kW or more
- Proton time distribution
  - Single-turn fast extraction of single bunches
  - Bunch length <~ 25 nsec
  - Bunch separation >~ one msec
- Creating the proton distribution in the Booster era
  - Momentum-stack three Booster batches in the Accumulator
  - Rebunch at ~26.4 MHz (one 100 nsec bunch in mu2e)
  - Single-turn transfer all 42 bunches to the Debuncher (single bunch in mu2e)
  - Extract bunches individually from the Debuncher (resonant slow-spill in mu2e)
  - Repeat the above sequence twice per MI cycle

Booster-Era Beam Timelines for g-2 Experiment

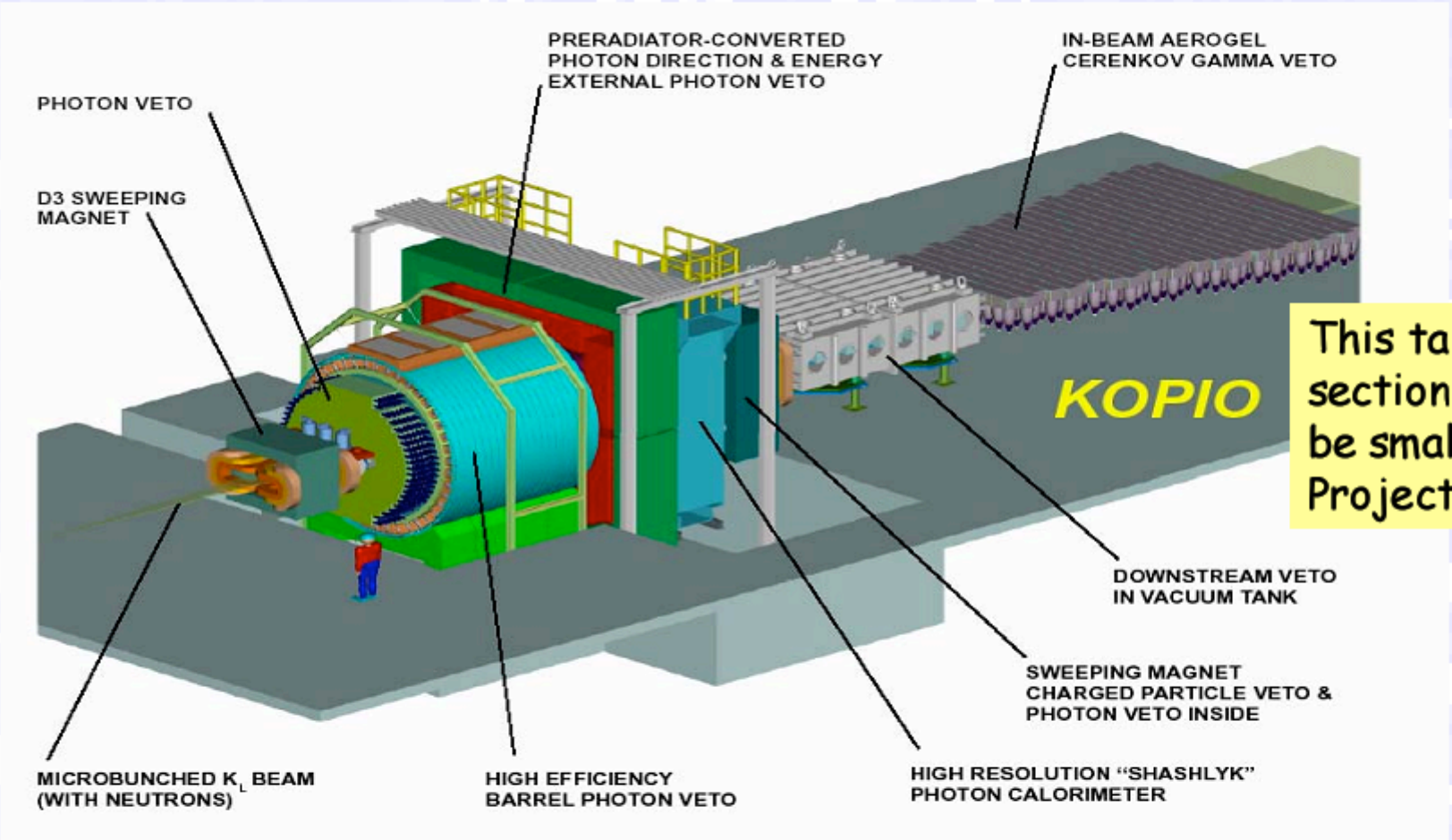
120 GeV to NovA

This is scheme showed in first talk



Can Slow Extract in a Range of Proton Pulse Lengths: 10 nsec shown

Neutral Kaon "Kopio" like detector space requirements....



This tail section will be smaller at Project-X

Transverse (elevation view) dimensions: 5mx5m maximum.

Longitudinal (plan view) dimensions : 10m (of 5mx5m) + 10m (of 3mx3m)

Rare K Decay Experiment Requirements

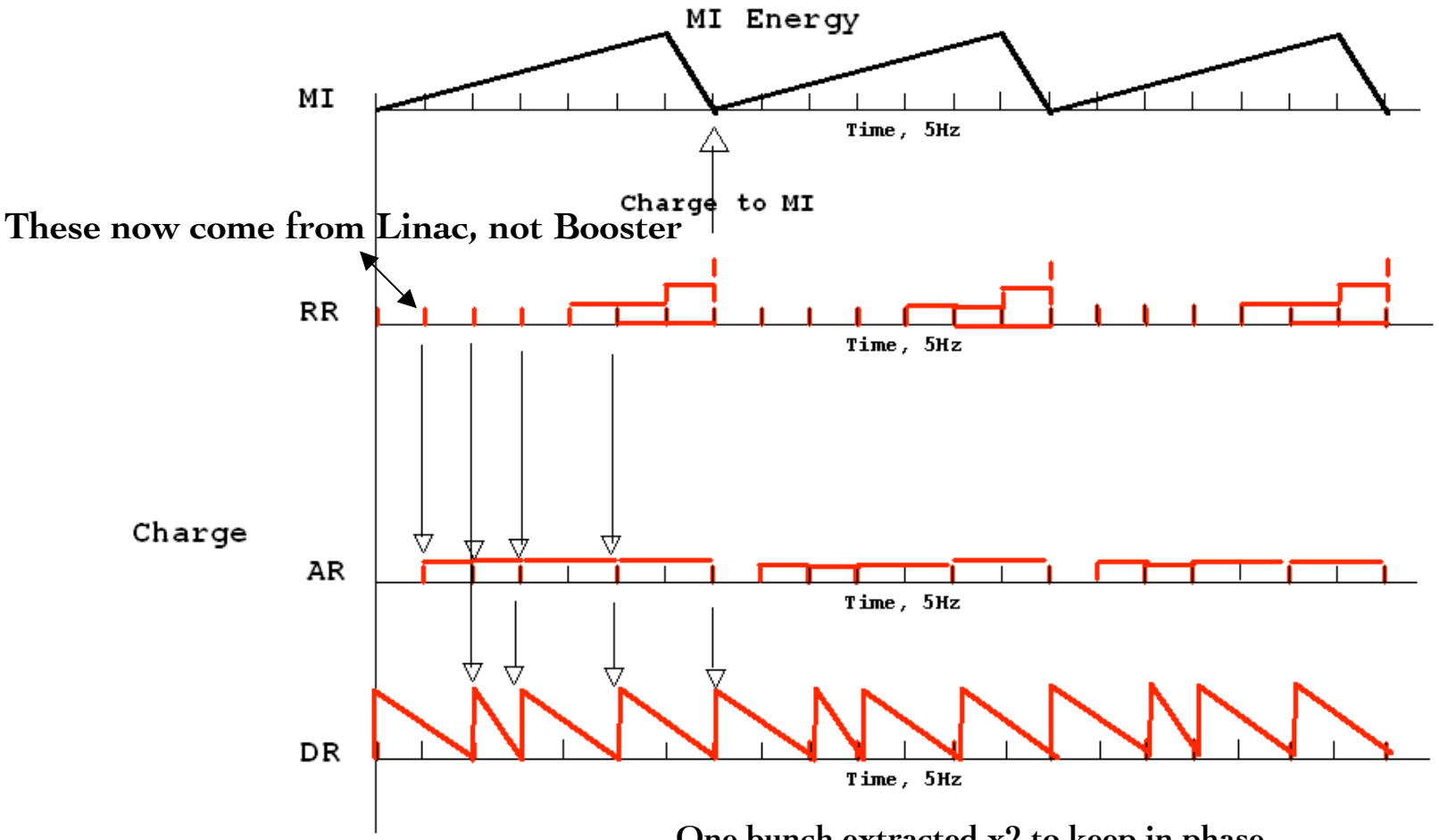
- Beam Power
  - Booster era: ~ 25 kW
  - Project X era: 200 kW or even more
- Proton time distribution for KOPIO-like experiment
  - Slow spill with high duty cycle
  - Bunch length <~ 300 psec (the shorter the better)
  - Bunch separation ~ 40 nsec
- (Charged K exp't can use KOPIO beam time structure)
- Creating the proton distribution in the Booster era
  - Momentum-stack three Booster batches in the Accumulator
  - Rebunch at ~26.4 MHz
  - Single-turn transfer all 42 bunches to the Debuncher
  - Add high-frequency rf harmonics of 26.4 MHz to ring voltage
    - Center of bucket slightly higher momentum to get short bunch length
  - Resonantly extract that perturbed piece from the Debuncher
  - Repeat the above sequence twice per MI cycle

Can This Work for Project X?

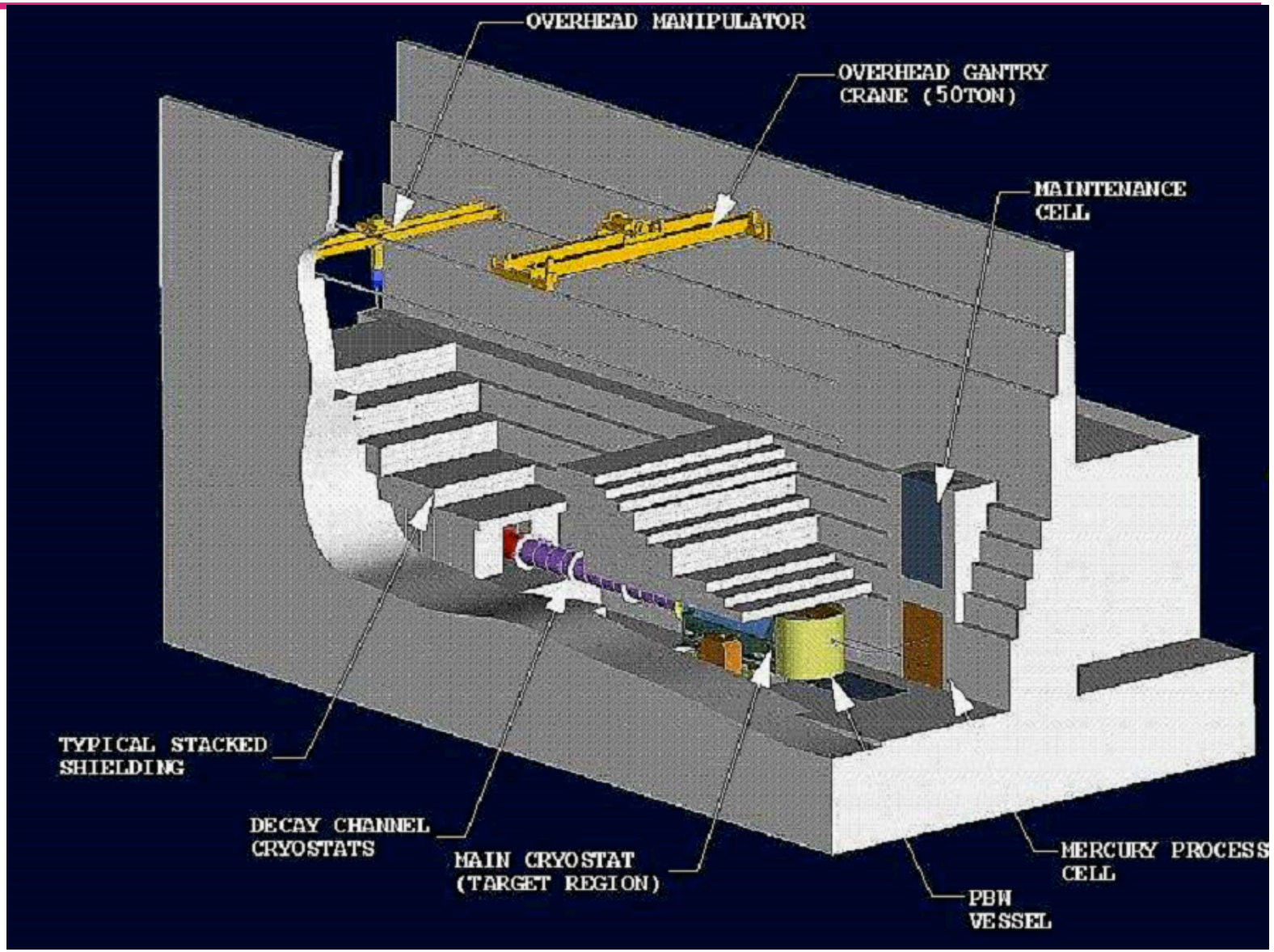
- Assumption of < 200 kW/ring
- Each "pulse" from Linac about 50 kW
- Manipulate beam to keep four pulses (< 200 kW) in any ring

- If Upgrades to Project X, will need to rethink all schemes!

One Possible Set of Beam Timelines for Project X Era



2 MW Target Station for ν Factory or Muon Collider



Summary: Advantages of the Proposed Plan

- Flexible
  - Experiments can start with Booster beam, then transition to beam from Project X without relocating.
  - Beam time can be shared flexibly.
- Economical
  - Existing infrastructure is intensely used.
  - Only one new short tunnel to begin
  - Only one new high-power target station/exp't hall
  - All (or most?) 1st-round experiments located in one area
- It can be implemented rapidly.
  - The new tunnel could be built soon
- It provides a path back to the energy frontier.
  - Target station is located in line with a long-term plan